4.6 Mongaup River from Swinging Bridge Reservoir to Mouth

4.6.1 Setting

The Mongaup River segment (Figure 4.8) extends 17 miles from the Swinging Bridge Reservoir outlet structure (seven miles southwest of Monticello, New York) to the confluence with the Delaware River. Swinging Bridge Reservoir and two downstream reservoirs, Mongaup Falls Reservoir and Rio Reservoir, generate hydropower. Two other reservoirs on Black Lake Creek (a Mongaup River tributary), Toronto Reservoir and Cliff Lake Reservoir, provide additional storage for the Mongaup system upstream of Swinging Bridge Reservoir.

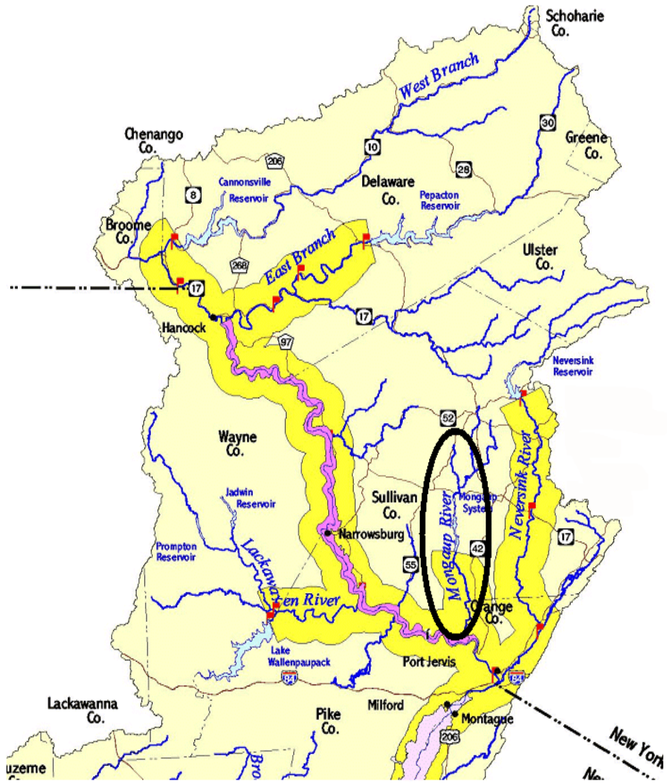

Figure 4.8
Mongaup River

The Mongaup reservoirs are owned and operated by Mirant New York, Inc. as peak electric-generating facilities, and occupy 10.5 miles of this segment. The short, free-flowing reaches downstream of the Swinging Bridge Reservoir reach occupy narrow, heavily wooded valleys. The reach downstream from Rio Reservoir is wilderness-like in appearance. For most of the run, the floodplain and valley walls are state-owned, the river has a steep gradient, and there are no roads close to the channel.

Summer hydropower releases are generally limited to several hours per day, Monday through Friday, to coincide with peak electrical energy demands in the northeastern United States. Hydropower releases from Rio Reservoir are generally 435 cfs (one turbine) or 870 cfs (two turbines).

Coincident with the FERC relicensing process (application made Sept 9, 1988; license granted April 14, 1992), a Memorandum of Understanding (MOU) between Orange & Rockland Utilities, Inc. (O&R, the prior owner) and the NYSDEC established minimum conservation releases to the Mongaup River. The minimum conservation release rates under normal conditions are 100 cfs from Swinging Bridge and Rio Reservoirs and 70 cfs from Mongaup Falls Reservoir. The NYSDEC classifies the free-flowing portions of the Mongaup River downstream from each reservoir as B(T) – suitable for trout propagation and survival. The new FERC license also requires scheduled weekend releases for boating purposes. During drought emergencies, the DRBC has the authority to reduce conservation releases and curtail power releases in order to refill the Mongaup Reservoir system by June 1.

From Rio Reservoir to the river's mouth 4.5 miles downstream, the river contains wild (propagating) brown trout and is considered an outstanding trout fishery. Power generation releases from Rio enter the river 1.5 miles downstream of the dam, and most recreational boating occurs in the last three miles of the river.

4.6.2 Issues

Flow in the Mongaup River depends on both the conservation releases and hydropower releases from the Swinging Bridge, Mongaup Falls, and Rio Reservoirs, and thus is highly variable. The following issues were identified for this segment:

- Section 4.6.2.1 Fish habitat/water quality
- Section 4.6.2.2 Recreational boating

The water quality issue relates to dissolved oxygen (DO) levels in reservoir releases. Studies conducted for the relicensing process found low DO levels in the hypolimnetic zone of the reservoirs. Consequently release water entering the free-flowing portions of the Mongaup River at times was lower than the Class B(T) water minimum criterion (5.0 mg/l). The FERC license required a study to determine means to modify releases so as not to violate the NYSDEC Class B(T) waters DO criteria. Based on the FERC relicensing docket materials and project interviews, there appears to be a general (but not universal) consensus that the habitat and recreational releases mandated in the 1992 FERC license and in the related MOU provide satisfactory trout habitat, fishing, and boating conditions in the free-flowing portions of the Mongaup River. The NYSDEC has expressed concern that the *drought emergency* releases called for in the DRBC Water Code could jeopardize fish habitat, however. Potential index displays are described below:

4.6.2.1 Trout Habitat

a) Trout Habitat

IFIM studies were conducted as a part of the FERC relicensing process, and minimum flow requirements have been established in the reservoir tailwaters. The IFIM results could be used to establish the loss of trout habitat caused by drought operations and the associated reductions in reservoir releases. The IFIM results could be combined with flow modeling results to determine the reductions or increases in habitat under alternative operating plans.

4.6.2.2 Recreational Boating

a) Recreational Boating Days/ Weekend Boating Days

Flows of 435 and 870 cfs (the releases with one and two turbines in operation, respectively) provide excellent whitewater boating opportunities. As mentioned above, weekend releases are scheduled once every two weeks. Flow modeling results can be used to determine the success of operating alternatives in achieving preferred boating conditions. Also, improved power generation forecasts would provide more lead time for boating during weekday periods, and displays similar to those discussed in Section 4.4.2 for the Upper Delaware could be used.

4.6.3 Additional Information and Study Needs - Mongaup River from Swinging Bridge to Mouth

All of the issues identified on the Mongaup River stream segment were investigated during the FERC re-licensing of Mirant New York, Inc., hydropower operations. Thus, good flow-benefit relationships generally exist for this reach. However, the DRBC OASIS model currently lacks the ability to model this system. Very recent work for the City of New York has produced an OASIS-based model of the system. Suggested actions for improving the ability to analyze Mongaup system alternatives include:

1) Add the Mongaup system reservoirs and their operations to the DRBC OASIS model.

2) Re-establish the USGS stream gage below Rio Reservoir as a means of providing flow data downstream of the reservoir.

4.7 Lehigh River from F.E. Walter Dam to Mouth

4.7.1 Setting

The Lehigh River segment (Figure 4.9) extends 77 miles from the Corps of Engineers-operated F.E. Walter Dam near White Haven, Pennsylvania to the river's confluence with the Delaware River at Easton, Pennsylvania. Along this course the river traverses portions of four Pennsylvania counties (Luzerne, Carbon, Lehigh, and Northampton) and three physiographic provinces (the Appalachian Plateau, Valley and Ridge, and the Piedmont). The reach between the dam and Jim Thorpe, Pennsylvania is primarily used as state game lands. River access is limited because there are no roads paralleling the river and few roads that cross it. Through much of this section the river flows through a narrow, steep-sided valley. In the 14 river miles between Jim Thorpe and Lehigh Gap, creeks draining lands once heavily mined for coal and zinc enter the river. The river is accessible at several locations along this reach. The Pohopoco Creek stream segment joins the Lehigh in this reach but does not drain any mined land. South and east of Lehigh Gap, the river gradient decreases as the river traverses rolling farm land before passing through a growing metropolitan area comprised of three moderate-sized cities – Allentown, Bethlehem, and Easton. The river is very accessible within this section.

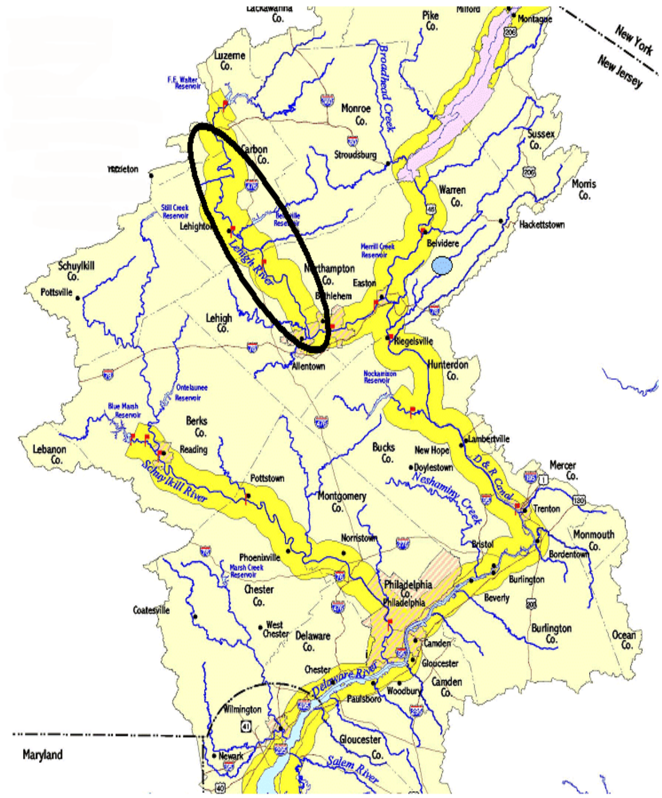

Figure 4.9
Lehigh River

The F.E. Walter Reservoir, a federal flood control facility completed in 1961, is operated by the Philadelphia District of the U.S. Army Corps of Engineers. In 1962, Congress authorized the Corps of Engineers to raise the dam to provide 23 billion gallons of additional storage for water supply while preserving the flood control storage. The water storage capacity could be used to meet downstream flow targets, replace consumptive uses and maintain critical low flows. The modification (a key issue addressed in the Good Faith Recommendations) has not yet been undertaken because funding has not been secured.

The reservoir has a current storage capacity of 35 bg and is operated to reduce flood stages on the Lehigh River at Lehighton, Walnutport, Allentown, and Bethlehem. A conservation pool currently estimated at 0.58 bg is available for maintaining a minimum release specified in the DRBC Water Code at 50 cfs. The Water Code specifies that this minimum release be reduced to 43 cfs under *drought warning* and *emergency* conditions. During the drought of 2001-2002, the Corps of Engineers provided temporary storage in F.E. Walter Reservoir while maintaining a minimum release from the reservoir of 156 cfs, if it was supported by inflow. Both warm and cold water fisheries exist in the Lehigh River. Brown and rainbow trout are stocked.

Public Law 100-676 (November 17, 1988) made recreation an authorized purpose of the project. Recreation was authorized on the lands associated with the project and on the lake itself, as well as downstream of the reservoir where whitewater recreation depends on upstream operations.

4.7.2 Issues

The following flow management issues were identified on the Lehigh River:

- Section 4.7.2.1 Use of F.E. Walter Reservoir for Flow Augmentation
- Section 4.7.2.2 Whitewater Rafting
- Section 4.7.2.3 Water Quality
- Section 4.7.2.4 Rapid Expansion of Small Independent Electric Generating Facilities
- Section 4.7.2.5 Drought Storage in F.E. Walter Reservoir

Because F.E. Walter is operated almost exclusively as a flood control reservoir, there is little downstream flow control. Regular supply of cold water to support a trout fishery has not been available. Up to five scheduled whitewater releases are made each year and there is a provision for emergency storage of water in the reservoir in advance of drought as mentioned above. Changes in F.E. Walter operating policies could provide flow augmentation benefits for whitewater rafting, establishment of a naturally reproducing trout fishery, and other purposes. Benefits would have to be weighed against any losses in flood storage volume and associated reduction in downstream flood control.

4.7.2.1 Flow Augmentation/Emergency Storage

The authorized purposes for F.E. Walter Reservoir are flood control and recreation. Minimum releases are maintained to the tailwaters, but there is no dedicated permanent pool of water available for support of the Trenton flow target or other downstream flow targets that could potentially be considered on the Lehigh River. The use of storage for such releases would require an assessment of the existing authority for operation of the reservoir as well as any spare flood storage capacity.

Flow augmentation at F.E. Walter would involve periodically raising the pool level. This would have important effects both downstream (as discussed above) and in the reservoir. In particular, some habitat surrounding the lake, including some wetlands, would be regularly flooded, and as a result, new habitat would develop along the new shoreline. Any boat ramps into the lake would be affected as well. Potential index displays include the following:

a) Storage at F.E.Walter

The impacts of operational changes on the storage in the reservoir are important from the standpoint of increased risk of downstream flooding, lake-related impacts (discussed above), and the amount of augmentation storage available for other purposes. This display should be a simple time series trace of simulated storage available for augmentation.

b) Downstream flood risk

Unless the dam was to be raised, the current flood storage capacity in F.E. Walter would be reduced if the flow augmentation storage pool were increased. One way to quantify the flood risk is to look at the simulated flood storage available at the start of historical floods. This display would consist of a table listing historical floods and the simulated flood storage available at the start of each flood.

c) Flows at targeted augmentation points

If F.E. Walter is used for flow augmentation, downstream targets will need to be met. Daily deviations from flow targets as described in Section 4.4.2.5 are a potential display related to meeting such targets.

d) Drought Management impacts

The use of flow augmentation from F.E. Walter to meet the Trenton flow target would reduce the frequency and duration of Lower Basin drought events by preserving storage in other Basin reservoirs. Displays for this issue include the number of days in *drought watch*, warning, and drought and minimum reservoir storage as discussed in Section 4.4.2.2

4.7.2.2 Whitewater Rafting

a) Whitewater rafting days

If F.E. Walter is used for additional flow augmentation, some additional whitewater rafting, canoeing, and kayaking benefits can be expected. The U.S. Army Corps of Engineers administers the whitewater release program for the reservoir and has data relating whitewater conditions to flow. This could be used with flow hydrographs produced by daily flow modeling to determine the number of days of preferred boating conditions for alternative operating plans.

4.7.2.3 Water Quality

a) Traces of water quality parameters and number of days values exceed criteria

Fishing and conservation organizations along the Lehigh River have supported the use of releases from F.E. Walter Reservoir to improve water quality in the river. The Lehigh River Watch has collected water quality information at several locations along the middle Lehigh. The Commonwealth of Pennsylvania, the DRBC, and the U.S. Army Corps of Engineers recently completed a water quality monitoring study of the Lehigh River, which constitutes the first step in developing a water quality model that can be used to relate water quality conditions to flow in the river. Comprehensive water quality modeling of the river might also require the development of water quality models for Beltzville and F.E. Walter Reservoirs. The combination of water quality and daily flow modeling could be used to determine the frequency of exceedance of water quality criteria for alternative reservoir operating plans. The correlation of reservoir release data with water quality observations would be a first step in determining the extent of modeling necessary to establish flow versus water quality relationships.

4.7.2.4 Increased Water Demand

a) Demand and shortage plots and tabular summaries

Time series plots of demands along the river and shortages (the extent to which the demand cannot be met) would be the primary index displays. Tabular summaries should include the total number of shortages, the number of days of shortages, and the number of shortage events. To more precisely model water demand, the DRBC OASIS daily flow model should be modified to distribute consumptive use throughout the tributary watersheds.

4.7.2.5 Drought Storage in F.E. Walter Reservoir

The issue of drought storage in F.E. Walter Reservoir is a subset of the issue of flow augmentation storage. During past drought emergencies, the Corps of Engineers has provided temporary storage at the request of the DRBC, but a permanent agreement to provide this storage is not in place. Modeled flows at White Haven, Lehighton, Walnutport, and Bethlehem could be used as an index to compare alternative drought flow augmentation programs for the reservoir.

4.7.3 Additional Information and Study Needs - Lehigh River

With the exception of the expansion of small independent electric generating stations, which will be addressed below, all of the identified issues on the Lehigh River stream segment are associated with the use of F.E. Walter Reservoir to regulate/augment flows for particular purposes, namely water quality, recreational boating, drought management, and maintenance of aquatic habitat. While the DRBC OASIS model can be used to assess the adequacy and impact on reservoir storage of any prescribed flow schedule, at this time our knowledge of the flow relationships is inadequate. The following steps are suggested, in priority order, for establishing additional flow relationships:

1) Evaluate the increased risk of downstream flooding associated with re-allocating a portion of the flood storage pool in F.E. Walter Reservoir to conservation storage. This would make more storage available for other flow management purposes.

2) Conduct a biological assessment of the Lehigh River below F.E. Walter Reservoir. In particular, the relationships between flow and water quality and flow and the maintenance of aquatic habitat are not well known.

   DRBC and the Corps of Engineers recently conducted a water quality study for the Lehigh. The data generated by this study, if used in conjunction with water quality modeling, should contribute to a better understanding the flow and water quality relationship. In particular, the relationship between releases from Beltzville Reservoir and water quality should be addressed. Additional information is needed about the current condition of the aquatic habitat and the extent to which flow management could improve conditions.

3) Document flow versus boating conditions based on available data.

4) Distribute projected increases in consumptive use with more precision in the DRBC version of the OASIS model.

5) Evaluate the need for reservoir water quality models for Beltzville and Blue Marsh Reservoirs.

4.8 Pohopoco Creek from Beltzville Dam to Mouth

4.8.1 Setting

The Pohopoco Creek segment (Figure 4.10) extends five miles from Beltzville Reservoir down to the Lehigh River. Beltzville Reservoir, located near Lehighton in Carbon County, is managed by the Corps of Engineers for flood control, recreation, water quality, and water supply.

The area is rural, primarily forested, and has very little urban development. Carbon County is on the periphery of the northeastern Pennsylvania counties that are growing rapidly.

The drainage area above the dam is 96 square miles. The permanent storage pool of the reservoir is 13 bg; an additional 8.8 bg is available for flood control. The DRBC owns about 70 percent of the permanent storage (9.1 bg), which is used for maintaining the Trenton flow target. The remaining 3.9 bg is federally owned and allocated for downstream water quality control and flow augmentation.

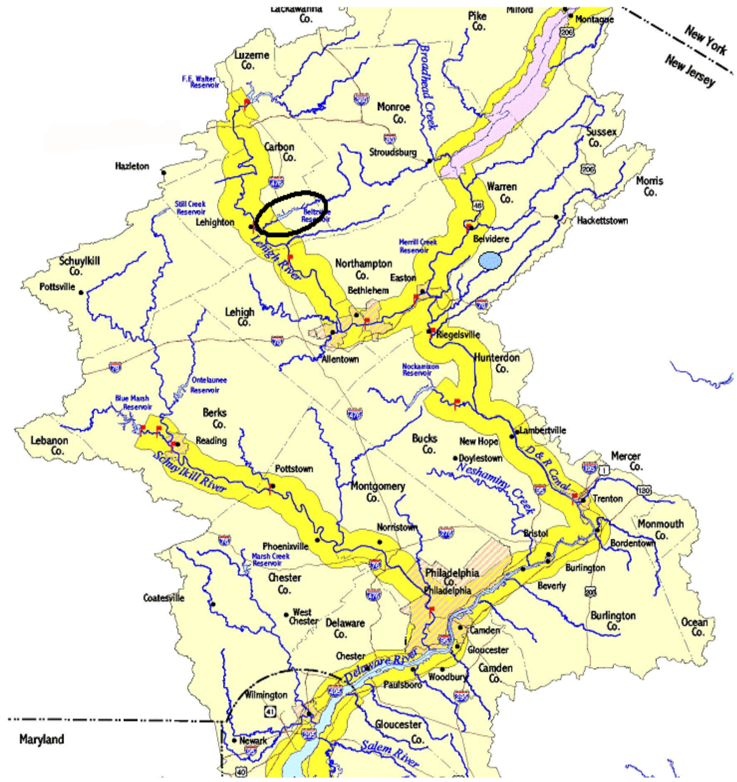

Figure 4.10
Pohopoco Creek

The stream is classified by the PADEP as a cold water fishery (CWF) suitable for the propagation and management of trout. There is a cold water conservation release from the reservoir. Under normal conditions, this release is 35 cfs, but it is reduced to 15 cfs during drought conditions.

Brown and rainbow trout are stocked in Pohopoco Creek downstream from the Beltzville Dam. Fingerling trout have been observed in the creek, but it is uncertain whether they were hatched from eggs spawned in the creek or were released from the reservoir. (Fingerlings are stocked in the reservoir.) Stream channel water temperature remains cold throughout the summer. The releases may even be colder than optimal through much of the spring and summer and productivity may be impacted. No IFIM or other fisheries studies have been performed in this section of Pohopoco Creek.

4.8.2 Issues

No specific instream flow management issues could be identified in Pohopoco Creek. There is a trout fishery in the creek, mainly from annual stocking of fish, but the current reservoir releases support this fishery adequately. Boating was not identified as an issue on Pohopoco Creek.

No recommendations for additional technical work have been made since no flow management issues were identified.

4.9 Tohickon Creek from Nockamixon Dam to Mouth

4.9.1 Setting

The Tohickon Creek stream segment (Figure 4.11) extends in a southeasterly direction from the Nockamixon Reservoir dam to the Delaware River at Point Pleasant, Pennsylvania. The stream flows through a largely rural and agricultural section of Bucks County, approximately eight miles north of Doylestown and just 30 miles north of center city Philadelphia. It is within a one-hour drive of more than two million people.

The portion of Tohickon Creek below the reservoir is classified as a cold water fishery. Although the Pennsylvania Fish & Boat Commission (PAF&BC) stocks trout, they report that few, if any, survive the summer's warm temperatures. The lower portion of the segment lies within Ralph Stover State Park and Bucks County parkland. Outside of the parkland, access to the creek is relatively limited.

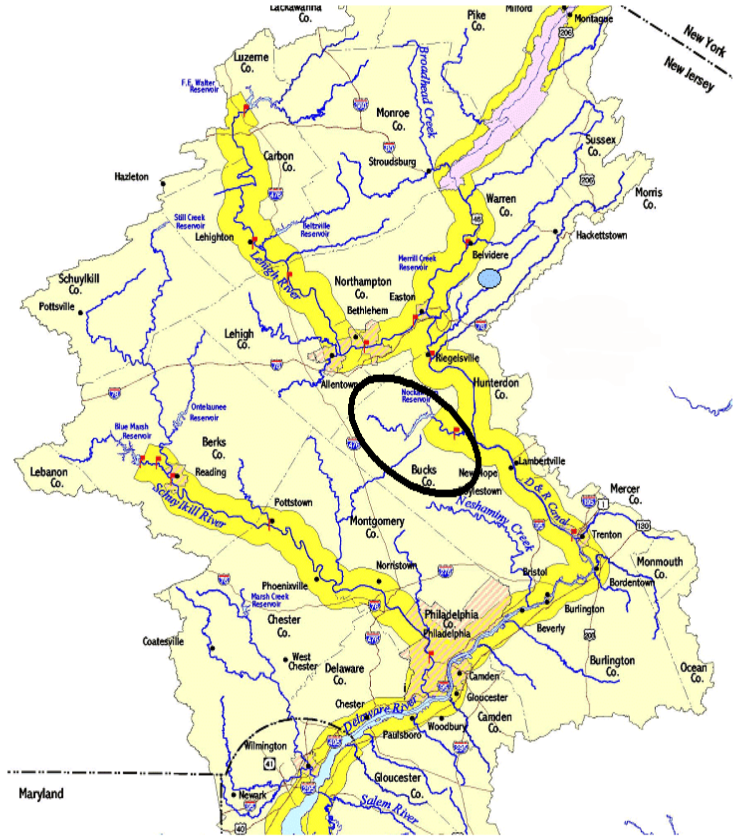

Figure 4.11
Tohickon Creek

Nockamixon Reservoir is owned and operated by the State of Pennsylvania as a recreational lake and is part of Nockamixon State Park. The dam's cold water conservation release was designed to be 12 cfs, but the actual release is on the order of 6 cfs. According to a PAF&BC representative, the reservoir lacks sufficient inflow to both maintain the recreational pool and meet the conservation release flow. The DRBC Water Code authorizes the Commission to direct releases from the reservoir to maintain the Trenton flow target during drought emergencies.

4.9.2 Issues and Analysis

The following flow management issue was identified for Tohickon Creek:

- Section 4.9.2.1 Recreational Boating

Below Nockamixon Dam, the Tohickon Creek is stocked with trout each spring, but the trout do not survive the warm summer. During the two annually scheduled releases from the dam, the stream becomes a world class kayaking venue. Since inflow is limited, additional releases for fisheries or kayaking would impact lake levels and reduce lake recreation benefits. Lake Nockamixon is also a valuable recreational resource with a large marina area for sailboats and motorboats of less than 10 horsepower.

4.9.2.1 Recreational Boating

a) Days of scheduled kayaking releases

Releases of about 760 cfs produce world class whitewater for kayaking downstream of Nockamixon Dam. Two such releases are currently scheduled each year. Inflow forecasts might make it possible to schedule additional releases in the spring of wet years without jeopardizing summer lake levels. The index display would indicate the number of actual kayaking events over a simulation run. The National Weather Service is expanding its deployment of Advanced Hydrologic Prediction Services (AHPS) products, which include 30-day inflow forecasts for major reservoirs. If developed for Nockamixon Reservoir, this would improve forecasting capabilities for potential additional whitewater releases.

4.9.3 Additional Information and Study Needs - Tohickon Creek

The only issue identified in this stream segment was the lack of water to fully meet three demands on the resource: conservation releases, whitewater releases for the two scheduled events per year, and the maintenance of lake levels for recreation. All of these uses are ultimately under the jurisdiction of the State of Pennsylvania, and enough is known about the flow requirements and the storage available in Nockamixon Reservoir for this issue to be evaluated. Both the local and Basinwide implications of such changes can be evaluated using existing information and the DRBC version of the OASIS model.

4.10 Delaware Estuary and Bay from Trenton to Mouth

4.10.1 Setting

The Delaware Estuary segment (Figure 4.12) includes the Delaware Bay and the tidal portion of the Delaware River. The drainage area extends from Trenton, New Jersey and Morrisville, Pennsylvania to the mouth of the Delaware Bay at Cape Henlopen, Delaware and Cape May Point, New Jersey. The Estuary is 135 miles long and has a drainage area of 5,985 square miles (including the entire Schuylkill watershed), or approximately 47 percent of the Delaware River Basin.

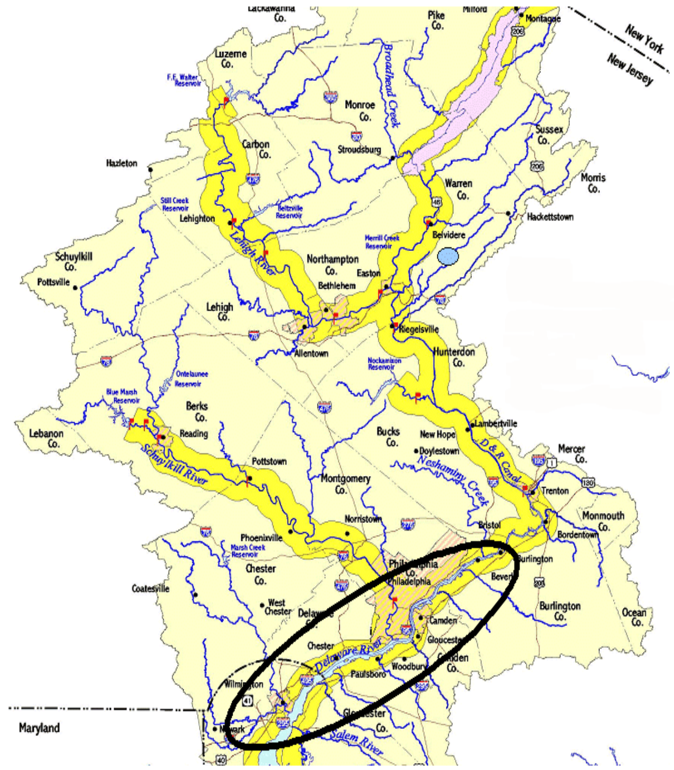

Figure 4.12
Delaware Estuary

The region is a major industrial center, and the Delaware Estuary serves as a navigation link to world markets. The Estuary also provides an expanding recreational resource for boating and fishing, serves the water supply needs for major population centers, and supports an area of unique and abundant biodiversity.

Over five million people reside in the 13 counties of Pennsylvania, New Jersey and Delaware that border the Estuary. Major urban areas include Trenton and Camden, New Jersey; Philadelphia, Pennsylvania; and Wilmington, Delaware. Heavy industry is concentrated along the water and is supported by a 40-foot dredged navigation channel that is authorized to be deepened to 45 feet. The Estuary includes access channels to the Ports of Philadelphia (a major U.S. port), Wilmington, Camden, and Trenton, as well as to the Chesapeake and Delaware Canal, which connects the region to the Port of Baltimore.

The estimated 1999 population of the region was 5,120,000 -- two percent of the total United States population and about 25 percent of the total combined population of the States of Delaware, New Jersey, and Pennsylvania. The population for the region has increased only 2.2 percent since 1970, but population shifts within the region have been dramatic. The area has been affected by heavy out-migration from the City of Philadelphia and other urban centers to the suburbs.

The Estuary has a history of water quality problems, which peaked during World War II, when the pollution was "…so bad that sailors and dock workers were often nauseated by the river's odor." (Majumdar, S.K. editor, et al., 1988; Albert, R.C, 1987; Delaware Estuary Program, April 1996.) Following the adoption of DRBC's more stringent water quality standards and massive investments in wastewater treatment, water quality has improved substantially. Some water quality standards are still not met in the Philadelphia metropolitan area, however.

A major resource for this study was The Scientific Characterization of the Delaware Estuary, (Sutton, C.C., O'Herron, II, J.C., and Zappalorti, R.T., April 1996). The goal of this report was "to integrate and synthesize historic, recent, and ongoing research and information for the purpose of defining priority problems (and their causes) in the Estuary." The Characterization report lists the goals and objectives of the Estuary Program. Some of the specific objectives relevant to flow management were to:

1. Restore population levels of harvestable species of finfish and invertebrate species to levels that will support sustainable recreational and commercial fisheries;
2. Restore or maintain populations of estuarine-dependent amphibians, reptiles, and mammals;
3. Maintain or restore an assemblage of organisms and their habitat throughout the Delaware Estuary and tidal wetlands that contribute to the ecological diversity, stability, productivity, and aesthetic appeal of the region;
4. Ensure an adequate supply of freshwater to the Estuary to maintain habitats, distribution of salinity, and human population in 2020;
5. Develop programs and actions that will be mutually beneficial to both the economy and environment of the Estuary, by forging a partnership with industry, commerce, and local governments.

Because freshwater mixes with the ocean saltwater to create the salinity patterns in the Estuary, and because waste assimilation in the Estuary is affected by freshwater flows, estuary inflow affects the ability to achieve each of these objectives.

Inflow to the Estuary is affected by upstream reservoirs in the Delaware River Basin, which have a combined storage capacity of approximately 500 billion gallons and control approximately 30 percent of the total drainage area. The reservoirs reduce flood peaks and increase low flows over what would naturally occur. In relative terms, the affects on low flows are the most pronounced. During the severe mid-Basin drought of 1999, as much as 50 percent of the measured flow at Trenton was made up of reservoir releases.

According to the Characterization report, over the past 50 years, "upstream intrusion of saline waters from the Estuary has also increased…." While this may apply to lower portions of the Bay and Estuary, analysis of chloride data by the DRBC staff shows no trend toward increasing salinity intrusion at Chester, Pennsylvania, over that time. In the upper Estuary, increased storage capacity since the 1960s and increased flow augmentation from the reservoirs above that which occurred in the 1960's drought has compensated for the effects of increased consumptive use, channel deepening, and sea level rise. Over time, assuming that the existing flow targets remain in place, additional channel deepening, increased consumptive use, and expected continued sea level rise, can be expected to increase salinity intrusion. Any proposals to modify releases from the NYC and other reservoirs should be evaluated in terms of the impact of associated changes in estuary inflow and concerns by Lower Basin states that the benefits of the existing release program not be jeopardized.

4.10.2 Issues and Analysis

The following flow management issues were identified for the Delaware Estuary and Bay:

- Section 4.10.2.1 Potable Water Supply Protection
- Section 4.10.2.2 Industrial and Municipal Impacts From Salinity
- Section 4.10.2.3 Base Flows, Permits and TMDLs, Waste Load Allocation
- Section 4.10.2.4 Freshwater Wetlands (Habitat), Fish Habitat
- Section 4.10.2.5 Oysters and Salinity Intrusion

The potential five-foot deepening of the Delaware River navigation channel has also been an issue in the Estuary. Table 5-1 of the Delaware River Main Channel Deepening Project - Supplemental Environmental Impact Statement, shows results of chloride modeling performed by the U.S. Army Corps of Engineers which indicates that the deepening would increase the 30-day average chloride levels by approximately 45 mg/l (channel bottom) at river mile 98 in the Camden/Philadelphia area during extreme drought conditions. Additional chloride modeling to examine the combined effects of channel deepening, and projected sea level rise has been requested by the DRBC. The models are in place for the Corps to conduct this analysis.

An additional related concern is future public water supply withdrawals from the Delaware. Although in-basin demand projections do not indicate major growth in this sector during the next 30 years, the Supreme Court Decree gives the State of New Jersey the right to export water from the Basin if the State builds additional storage and provides compensating releases. For this reason, the New Jersey Department for Environmental Protection (NJDEP) is concerned about the impacts of any proposals that would diminish releases past the Montague gage or inflows to the Estuary.

Potential index displays to evaluate the impact of alternative management strategies for these issues are described in the following sections.

4.10.2.1 Potable Water Supply Protection

a) Daily trace of chloride concentrations

This index display can be based on the results of a salinity model run in conjunction with (preferably in parallel with) an OASIS run. The DRBC salinity model used for estuary chloride analysis during the past 20 years does deal accurately with potential channel modifications. A regression derived from DRBC salinity model results relating estuary inflow to salinity intrusion is included in the DRBC version of the OASIS model. Improvements to salinity modeling capabilities are needed to account for changes in channel geometry when flow management policy alternatives are considered.

b) Estimated extent of chloride intrusion in the P-R-M Aquifer

The Camden Aquifer provides an important source of drinking water for southern New Jersey. Increased levels of salinity in the Estuary, in conjunction with sea level rise and induced infiltration caused by ground water withdrawals, may increase the extent of salt intrusion in the aquifer. The U.S. Geological Survey has developed a particle tracking model that predicts aquifer chloride concentrations based on pumping rates and assumed levels of estuary chlorides. If coupled with output flow hydrographs from the DRBC OASIS model, the effects of alternative operating policies on P-R-M chloride concentrations could be predicted. The USGS modeling has shown that estuary chloride concentrations required to render P-R-M supplies non-potable exceeds the existing chloride standard of 250 mg/l for protection of surface water uses in Zone 3 of the Estuary.

4.10.2.2 Economic Impact of Salinity on Industrial Water Users

a) Cost of chloride intrusion

The Corps of Engineers has investigated the treatment and increased process costs associated with salinity levels in the Estuary, but the work is 20 years old and portions of the work should be updated. A potential index display for this particular issue would present the sum of the treatment and process costs associated with the salinity traces produced by a long-term run of the salinity model under a particular management alternative. Upgrading salinity modeling capabilities and salinity cost data are required for this work.

4.10.2.3 Waste Load Allocations and TMDL-related Issues

Waste load allocations for the Estuary have been developed based on the minimum Trenton flow targets specified in the DRBC drought operating plan. It is essential that the impacts of any changes in the low flow regime on water quality and waste load allocations be quantified for flow-related policy changes to be considered. This applies to biological oxygen demand (BOD) loadings as well as allocations that may be developed for toxic substances. The impact of inflow changes at Trenton on the thermal loading in the vicinity of Duck Island has been raised as a concern by the NJDEP.

All of the displays in this section will require water quality modeling of the Estuary. In addition, GIS mapping of the relevant physical features will be required to produce the graphics in the potential displays.

a) Animated Displays of Concentrations of Critical Pollutants

BOD, dichloroethane (DCE), and tetrachloroethane (TCE), are currently subject to Waste Load Allocations (WLA) in the Delaware Estuary. WLA determine how much treatment is required for water dischargers and can have significant financial implications. Because of the nature of the methods used to compute Total Maximum Daily Loads (TMDL), which form the basis for WLA, alternative flow management strategies may impact WLA. Inflows affect both the concentrations of pollutants in Estuary inflows and the circulation patterns in the Estuary. Both of these affect the final concentration of pollutants, which is the starting point for computing both TMDLs and WLAs.

Because estuary dynamics are so complex, it is difficult to determine a critical condition for setting TMDL and WLA for an estuary. An animated display of the concentration of critical pollutants in the Estuary offers an approach to evaluating whether or not standards are met. Developing an animated display involves feeding the results of an Estuary water quality model into a GIS-based display system. Inputs to the water quality model would include inflow hydrographs generated by the DRBC OASIS model or an assumed minimum inflow condition. The DRBC has had an Estuary water quality model developed which includes salinity modeling capabilities. The model is presently being evaluated by the DRBC modeling and monitoring staff.

b) Maps of maximum concentration and percent of time criteria are exceeded for critical pollutants

Such maps would allow the user to establish whether or not standards are met and would be derived from flow and water quality modeling.

4.10.2.4 <u>Freshwater Wetlands Habitat, Fish Habitat</u>

Information related to potential and established relationships between flow management and the health of biological systems within the Bay and Estuary were sought out in interviews with staff of the Academy of Natural Sciences, DNREC, NJDEP, and by literature review. With the possible exception of the oyster/predator relationship, no such relationships were found. (For upstream migrating species, migration success is controlled by environmental factors or triggers other than flow. For downstream migration of young in the fluvial sections of the tributaries (not the Estuary), flow may be a factor in predation of young.)

The NJDEP (Miri) notes that the upper Estuary has recently hosted fishing tournaments for largemouth bass, and that striped bass as large as 50 lbs. have been caught in this area. This fishery is dependent on water quality, which is related to Estuary inflow.

Wetlands are influenced by the patterns of salinity intrusion over time. This pattern is affected by Estuary inflow, and would be further affected by sea level rise and deepening of the shipping channel.

a) Animated displays of salinity and important pollutants with a wetlands overlay

The exact nature of the influence of salinity on the viability of wetland ecosystems is poorly understood. Thus, the best displays for evaluating impacts are likely to be animations of predicted salinity for long periods. This would allow biologists to understand the range of salinities and the frequency of extreme events in more concrete terms than with simple tables and charts. This type of display would also use an improved salinity model in conjunction with the DRBC OASIS model.

4.10.2.5 <u>Oysters and Salinity Intrusion</u>

The ecology of oysters in the Delaware Bay, in particular the decline of oyster populations due to predators and disease, has been the topic of much research, much of it conducted by Haskins and Ford. Several references to this work are included in the publication entitled “The Scientific Characterization of the Delaware Estuary,” published by the Delaware Estuary Program, (Sutton, C.C., et.al, 1996, Chapter 7: Living Resources and Their Habitat.) This report summarizes the factors known or suspected to have contributed to the decline of oyster populations and commercial harvesting in the Bay. Researchers attribute the spread of MSX, a protozoan parasite that preys on seed oysters, at least in part to drought and resulting higher salinities. In addition, they attribute reductions in this predator to relatively low salinities in the Bay following tropical storm Agnes in 1972. The drought of 1985 is cited as causing higher salinities and more MSX. In 1990, another parasite, Dermo, entered the Bay and became a new cause of oyster damage. The reference does not discuss a relationship between Dermo and salinity, but does note that Dermo was probably introduced from the Chesapeake Bay, where it has decimated oyster stocks since the 1950s.

a) Animated displays of salinity and important pollutants with a wetlands overlay

These displays would overlay the model results for salinity or other parameters with maps of oyster habitat. Maps of oyster habitat have been developed in the course of the Corps of Engineers' channel deepening project. These types of overlays should help ecologists determine overall impacts of physical changes to the Estuary and changes in flow management.

b) Trace of the position of the 15 ppt isohaline

Work in the Level B Study (DRBC, 1981) demonstrated that the flow management afforded by Basin reservoirs affected chloride levels over the oyster beds, but that the impact was only one-tenth of the annual variation in chloride levels. There is some knowledge concerning the benefits of periodic episodes of lower (<15 ppt) salinity in reducing the impact of oyster parasites. It is not clear, however, that flow management by way of reservoir releases during low flows can have a significant impact on controlling the natural variations in the 15 ppt isohaline.

MSX and Dermo have difficulty surviving when salinity falls below 15 ppt. Thus, oyster bars in areas where salinity falls below this level for a significant part of the year tend to be protected from these parasites. This display will be informative to those familiar with occurrence and health of oysters in the Estuary. This display will also require incorporation of an improved salinity modeling capability with the DRBC OASIS model. The ability to predict the movement of the 15 ppt line will be useful in the implementation of oyster enhancement efforts now being proposed for the Delaware Bay.

4.10.3 Additional Information and Study Needs - Delaware Estuary and Bay

Conditions in the Delaware Bay are influenced by factors other than flow, most notably the point and non-point source pollution that occurs throughout the Basin. The following steps are suggested, in priority order, for establishing additional flow relationships:

1) Incorporate a new salinity versus flow relationship in the DRBC OASIS model. This salinity relationship should be capable of reflecting changes in the geometry of the Delaware ship channel, which might be accomplished by developing a separate relationship for each geometry. The new relationship should be based on the Corps of Engineers' new three-dimensional model of the Estuary or on the new water quality model recently developed for the DRBC's Monitoring and Modeling Branch. (The previously used DRBC salinity model is a two-dimensional (length and depth) model that cannot deal accurately with channel modifications.)

   Currently the DRBC OASIS model uses a regression fit to the current DRBC salinity model. It was adjusted "by eye" to achieve a reasonable model-to-model fit for the purposes of this study. The current regression fit is extremely crude and in need of upgrade. Either of the new models developed for the Corps of Engineers or the DRBC could provide the basis for improved representation of salinity in the DRBC OASIS model. A regression or neural network fit to these models, calibrated for low flows, would be much more appropriate. It is also appropriate to directly link DRBC OASIS and one of these models for detailed confirmation of selected runs made using the regression or neural network fit. The problem with using the direct linkage to the Corps' model for all runs is simply one of computational burden.

   In addition, the work previously completed by the Corps of Engineers to develop salinity versus cost functions for Estuary water users should be evaluated and updated to reflect newer information.

2) Evaluate and update the salinity intrusion versus industrial and public water supply cost information originally developed by the Corps of Engineers in the early 1980s. This information is needed to

evaluate the relationship between Estuary inflow and salinity-related costs to water users.

3) Pursue final peer review and publication of the USGS particle tracking study to document the relationship between Estuary chlorides and P-R-M salinity and evaluate whether the coupling of an Estuary salinity model with this particle tracking model is necessary or feasible. (Note: This recommendation has been included at the request of the DRBC staff.)

4) Develop and fund studies to better understand the ecology of the Estuary and the impacts of changes in the freshwater inflow regime during droughts.

   The research concerning the role of freshwater in the ecology of the Delaware Bay is sparse, perhaps because there were other causes, such as pollution, that were hypothesized to have a greater and more immediate adverse impact. The out-of-Basin diversions and the releases from the reservoirs have changed the volume and timing of inflow to the Estuary. The effect of regulation by the reservoirs in the Basin on the amount of freshwater entering the Bay is most pronounced during periods of prolonged drought. During these periods, flows are maintained at a higher level than would have occurred in an unregulated system. During normal and high flow periods, less inflow enters the Estuary due to out-of-Basin diversions (up to 800 mgd to New York City and 100 mgd to the State of New Jersey) and flow skimming by the reservoirs. Considerably more research is needed to establish impacts of the rate and timing of freshwater inputs from the current system or any alterations that may be proposed.

5) Use water quality models to evaluate the relationship between freshwater inflow and water quality in the Estuary. DRBC has developed such a model for the upper Estuary. This needs to be used to better understand the relationships on a large scale. The existing modeling capabilities for the Estuary should be evaluated in terms of the additional work needed to analyze such processes as eutrophication, sediment interactions, and biomass transport and their relationship to inflow. Relationships between water quality parameters and ecological indicator species should be incorporated with the water quality modeling.

4.11 Tulpehocken Creek from Blue Marsh Dam to Mouth

4.11.1 Setting

The 6.7 mile study segment of Tulpehocken Creek (Figure 4.13) is downstream of the U.S. Army Corps of Engineers' Blue Marsh Reservoir and upstream from the Schuylkill River. The drainage area of the creek above the dam is 175 square miles of mostly gently sloping farm and woodland in Berks and Lebanon Counties, Pennsylvania. Downstream from the dam, the creek is highly accessible to the public as it flows entirely through state, county, and city parks to the Schuylkill. Tulpehocken Creek has become a highly regarded cold water trout fishery because of the releases from Blue Marsh Reservoir. The dam has a multiport outlet works that permits control over the temperature of the release by allowing water to be taken from varying depths in the reservoir.

Figure 4.13
Tulpehocken Creek

Blue Marsh Dam is within six miles of Reading, Pennsylvania, a metropolitan area of over 213,000 people, about 65 miles from Philadelphia. The region supports many major industries, including primary metals, electrical and non-electrical machinery, equipment and supplies, food processing, and fabricated metals products. Reading is also a destination for tourists and discount retailing. Agriculture and forestry are the primary land uses, as only about 20 percent of Berks County is urbanized.

Put into operation in 1978, Blue Marsh Reservoir provides flood control storage (10.6 bg winter, and 8.8 bg summer), DRBC-owned storage for maintaining Estuary inflow (2.6 bg), water quality protection storage (2.2 bg), and recreation. The recreational uses of the park site and the creek below the dam include picnicking, swimming, boating, and fishing. Point and non-point sources of pollution in the headwaters of the lake cause water quality problems and sometimes curtail recreational activities. In general, however, releases are of high quality. The minimum release requirement during non-drought conditions is 50 cfs. Nine cfs can be withdrawn from the creek by the Western Berks Water Authority (WBWA) at a point 1.2 miles downstream from the dam for public water supply. During DRBC Lower Basin *drought warning* or drought conditions, the conservation release can be reduced to 30 cfs (including the 9 cfs for the WBWA), but releases to help meet flow targets at Trenton frequently keep releases higher. Flows have exceeded 50 cfs 96 percent of the time and 30 cfs 99.5 percent of the time, which approximates the frequency prior to the dam's construction.

Reservoir water levels are typically raised from winter to summer pool during a two-week period beginning on or about April 1 of each year. To accomplish this increase, the discharge is typically held at 175 cfs below inflow for the two-week period. (175 cfs for two weeks is enough water to raise the pool from winter to summer storage levels.) Drawdown from the summer to the winter pool typically occurs during a two-week period beginning on October 1.

4.11.2 Issues and Analysis

The following flow management issues were identified for Tulpehocken Creek:

- Section 4.11.2.1 Trout Habitat and Recreational Fishing
- Section 4.11.2.2 Use of Blue Marsh Releases to Meet Trenton Flow Target

4.11.2.1 Trout Habitat and Recreational Fishing

Releases from Blue Marsh Reservoir have made it possible to establish a trout fishery below the dam. The river is stocked with both adults and fingerlings. Recent reports indicate that the wetted area available to insect larvae that provide food for the fish is limited by the releases made during the spring refill period. In particular, flows below 70 cfs seem to create a significant reduction in wetted area, which is a concern given that typical flows during the refill period may be as low as 50 cfs. In recent years, the timing of spring releases has been adjusted with this in mind. Alternative refill strategies, particularly those based on forecast inflows, may further improve this situation.

a) Trout habitat acres by year

The acres of habitat suitable for trout feeding (caddis fly development) can be determined from the minimum spring flow from an OASIS model run and the IFIM study done by the Corps of Engineers and the PAF&BC. The index display can be a bar graph indicating the annual value for the minimum area.

4.11.2.2 Use of Blue Marsh Releases to Meet Trenton Flow Target

This issue was cited by the Philadelphia District of the U.S. Army Corps of Engineers. It has been the practice of the DRBC, which owns some of the storage in Blue Marsh Reservoir, to count directed releases from Blue Marsh Reservoir toward the total directed release needed to meet the Trenton flow target. The rationale has been based on modeling which shows that the salinity control benefits are the same whether freshwater enters the Estuary near Trenton or at the mouth of the Schuylkill River. This rationale may not apply to other purposes for maintaining freshwater inflow, such as Estuary habitat, wasteload allocation, or maintenance of any Schuylkill River flow targets, if they are considered. Additional study of instream and Estuary parameters versus inflow is needed to support the development of release policy and operations for purposes other than salinity control.

4.11.3 Additional Information and Study Needs - Tulpehocken Creek

The only issue identified in this stream segment was the improvement of trout habitat and, coincidentally, recreational fishing. The maintenance of a healthy trout fishery in this segment is dependent upon the release of adequate cold water from Blue Marsh Reservoir. The ability of Blue Marsh Reservoir to maintain sufficient cold water for downstream temperature has been marginal during some years based on Corps of Engineers data. The following is recommended:

1) Develop a thermal model for Blue Marsh Reservoir.

2) Develop an instream thermal model for Tulpehocken Creek below the reservoir. Together, these models would allow better quantification of the cold water available and more effective utilization of releases targeted at maintaining both habitat and instream temperatures.

4.12 Schuylkill River from Confluence with Tulpehocken Creek to Mouth

4.12.1 Setting

The project's Schuylkill River segment (Figure 4.14) extends 77 miles from the river's junction with Tulpehocken Creek at Reading, Pennsylvania, to the river's mouth in Philadelphia where it enters the Delaware River Estuary. The river is characterized by generally modest gradients, a few very modest rapids, and several low dams constructed during the 19th century to support river and canal transportation and industrial water power. The Fairmount Dam in Philadelphia is the head of tide. Between Reading and Fairmount Dam, the river passes through rural, suburban, and urban portions of Berks, Chester, and Montgomery Counties and the Fairmount Park section of Philadelphia. Over three million people live in the area.

River access is relatively limited except within Philadelphia, where access is excellent. There are increasing miles of bike trails not far from the river's edge and increased interest in recreational uses of the river. Downstream of Fairmount Dam, recreational uses have been restricted due to limited access and water quality concerns. Water quality throughout the Schuylkill River has dramatically improved during the past 30 years due to the implementation of the Federal Clean Water Act and the attendant improvement in wastewater treatment.

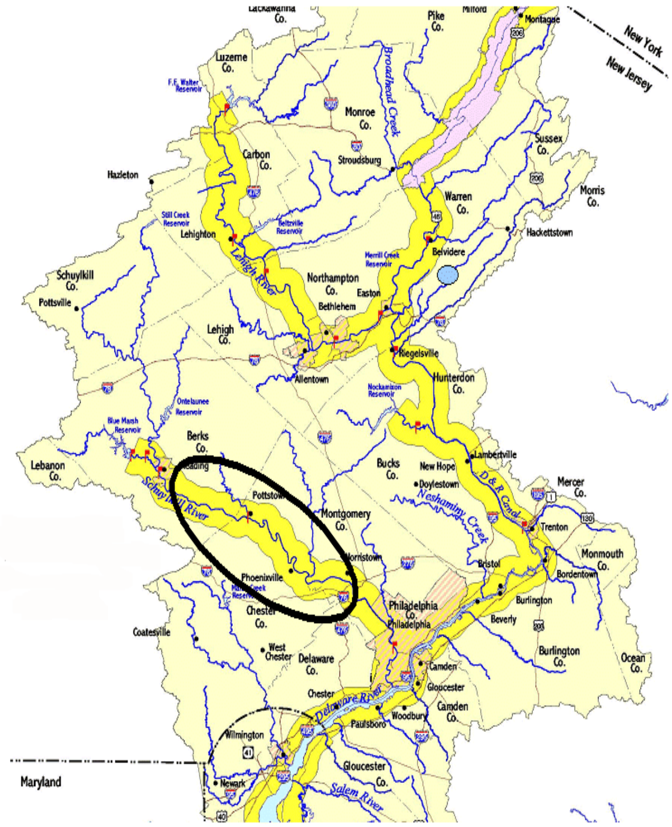

Figure 4.14
Schuylkill River

Water resources demands in the region are high due to the density of development in the area. The Schuylkill watershed leads all of the major tributaries in consumptive water use. During the summer months, the Point Pleasant diversion project replaces a portion of this consumptive use with water diverted from the Delaware River. The City of Philadelphia obtains approximately 50 percent of its water supply from the Schuylkill River. Much of the supply to areas outside of Philadelphia is from ground water. To address problems with ground water protection, the DRBC adopted Resolution No. 80-18 (effective date January 1, 1981), delineating a ground water protection area in southeastern Pennsylvania. The resolution was revised in 1999 to increase ground water protection in portions of Berks, Bucks, Chester, Lehigh Counties and all of Montgomery County. The resolution imposes limits on ground water withdrawals in order to avoid depletion of natural streamflows (ground water eventually seeps into streams) and to protect ground water quality.

4.12.2 Issues and Analysis

The issue of potential growth of water demand for power generation was identified as an issue for this stream segment based on the interviews conducted by HydroLogics. The DRBC staff cited several other areas of concern.

4.12.2.1 Increased power generation

Interviews revealed concern over the potential for large scale increases in consumptive use for power generation along the Schuylkill. Such increases could significantly lower flows in the river and, by extension, affect downstream water users (e.g., the Philadelphia water supply). The index displays needed to evaluate these issues are the same as those discussed for the Lehigh River (see section 4.7.2.4), and would show instream flows, and water demands and shortages.

4.12.3 Additional Information and Study Needs - Schuylkill River

The DRBC staff suggested the following information needs for the Schuylkill:

1) Obtain data relating boating quality and flow rates. The Schuylkill is a Pennsylvania-designated Scenic River, and data relating flow and boating quality should be assembled and correlated. An opportunity to collect such data could be provided through the annual Schuylkill River Sojourn.

2) Document the relationship between Blue Marsh releases and downstream improvement in dissolved oxygen (DO) levels. DO levels have historically been problematic in the Schuylkill. Additional work is needed to correlate releases from Blue Marsh Reservoir with increases in downstream DO conditions.

3) Determine the minimum flow requirements to maintain intake withdrawal capability at major Schuylkill River water supply intakes. At least five entities hold PADEP water allocation permits to withdraw water from the river below Reading for public water supply. The largest allocation is 258 mgd (400 cfs) to the City of Philadelphia. (The allocation was increased to 258 mgd from 200 mgd in 1957.) This flow is not always available. The minimum daily flow of record at Pottstown is 175 cfs (September 1932) and the minimum monthly low flow is 279 cfs (September 1964). To protect the City's supply, the water allocation permits held by the Borough of Phoenixville (7.0 mgd) and the Philadelphia Suburban Water Company (20 mgd) prohibit withdrawal when the flow in the river at Philadelphia is below 258 mgd. The permits held by the Pottstown Borough Authority (8.0 mgd) and the Pennsylvania-American Water Company (formerly Keystone Water Company and, prior to that, the Norristown Water Company) (17.5 mgd) are unrestricted.

4) Evaluate the potential growth of water demand for power generation. The DRBC staff cited the potential for large scale increases in consumptive use for power generation in the Delaware Basin. The geology of the Schuylkill makes it prone to low flows during drought periods and there is no established flow target for the stream. Significant increases in consumptive use could lower flows in the river and, by extension, potentially affect downstream water users (e.g., the Philadelphia water supply).

4.13 General Recommendations To Improve Analysis Capabilities and Promote Management Flexibility

HydroLogics recommends the following activities, applicable to multiple stream segments, in order to better understand the relationships between flow and benefits from a Basinwide perspective, and to increase flexibility in water resources management. The recommendations are grouped according to whether they are considered by HydroLogics to be either high or medium priority activities. It should be noted that a number of the recommendations call for development or refinement of modeling tools. Inherent in this recommendation is the need to evaluate the data collection networks required to support the modeling.

4.13.1 High Priority Recommendations

4.13.1.1 Extend and Improve the Inflow File Used as Input to the DRBC OASIS Model

DRBC is currently involved in a cooperative effort with the Corps of Engineers to extend the existing 60-year inflow file and determine a means of controlling modeled flow fluctuations at nodes where the fluctuations appear unrealistically high. The reasons this work is needed are the unrealistic variations in daily flows, particularly at low flows, output by the DRBC OASIS model, and the need to extend the inflow file from 1986 to 2000. The work includes extension of the inflow file data set, modification of the inflow file as necessary to reduce flow fluctuations, and inclusion of the reservoir operations of the Mongaup system in the DRBC OASIS model.

If the effort to control flow fluctuations is not successful, it is recommended that DRBC develop a new set of inflows using a methodology different than that used previously. The new methodology would involve first estimating local inflows on a monthly basis based on differences between gages and best estimates of historical consumptive use, even if these estimates are extrapolations at best. If the time of travel between gages is more than approximately one-half day, then the differences should be based on appropriately staggered records. The local monthly flows then need to be disaggregated to daily inflows based on local, unregulated, headwater gages. Given the gages and local inflows, the parameters of a Muskingum or lag-type routing equation can be estimated using regression. This equation could then be used to estimate time of travel. This would require modifying the "traveltimes.ocl" file in the DRBC OASIS model.

4.13.1.2 Improve Water Demand Forecasting Techniques for the Basin

The DRBC needs to be able to analyze impacts of water shortages in order to develop effective conservation and supply plans. In order to do this, it needs a more comprehensive method for forecasting demands than is currently available. The DRBC also needs updated water use data in order to evaluate trends. Developing the tools required for more sophisticated demand forecasts is, therefore, a high priority.

The DRBC staff and Basin states are in the process of updating the database to provide for an improved set of water demand projections. From a Basinwide perspective, the emphasis in assessing water demand has been on consumptive water use (water used but not returned to the Basin). Consumptive use impacts the amount of freshwater inflow to the Estuary, as well as losses of base flow in individual watersheds. The daily flow modeling database used with the DRBC OASIS model incorporates observed streamflow to generate historic inflow. All historic inflows, evaporation, and ground and surface withdrawals are included in these observations of streamflow. Modeling of future proposed operations relies on consumptive use forecasts to determine the additional loss of water over and above the historic conditions.

The techniques that have been used to forecast water demands in the Delaware Basin have not incorporated economically-based demand forecasting models. Such models account for growth in various economic sectors, seasonal and weather-related variations, and conservation practices and are readily available (e.g., IWR MAIN). These models can also estimate the economic benefits of water use and the costs of water shortages and, thus, improve the ability to define flow management versus benefit relationships.

4.13.1.3 Develop Toxic Spill Modeling Capability for the Delaware River and Major Tributaries

Many kinds of toxic material are regularly transported across and within the Basin. Given the dependence of the Basin on surface water, it is critical that the Commission have the means to predict the instream transport and fate of toxics when spills occur. This should include both the advection, dispersion, and degradation of toxics in the stream, and should become the basis for emergency response plans and exercises. This capability would allow the Commission to develop action plans and test them using exercises. The modeling required to track spills is different from the modeling needed to track flows, since flow modeling is based on the time of travel of hydraulic waves, and spill tracking requires modeling the movement of physical particles of water and pollutant. Spill tracking also requires knowledge of the fate of the pollutant in the environment, knowledge that may be lacking for some pollutants. Developing the models and other tools required is a very high priority. The DRBC is participating in the development of an early warning monitoring and tracking system financed by the City of Philadelphia.

4.13.1.4 Evaluate Forecasting Tools to Enable the Evaluation and Possible Implementation of Adaptive Management

Adaptive management is a process in which management strategies change in response to changes in the state of the water resources system, new scientific understanding of how management actions affect the system, and changes in management objectives. Implementing an adaptive management strategy requires monitoring of the things that might cause the management strategy to change - the state of the system, the progress of related science, and the management objectives. Without monitoring, adaptive management cannot be effective.

Forecasting tools predict the future state of the water resources system, and thus may be an important part of an adaptive management strategy. Using forecasting tools as a part of a management strategy broadens the range of alternatives and may dramatically improve the ability to manage for important objectives. We suggest that DRBC work with the National Weather Service (NWS) to apply products from the Advanced Hydrologic Prediction System (AHPS) to flow management. The NWS has available rainfall-runoff-based models that could be implemented for the entire Basin. These would provide medium-term probabilistic forecasts of inflow in Extended Streamflow Prediction (ESP) format. These forecasts may be useful in anticipating potential droughts, setting seasonal targets for maintaining cold water fisheries below reservoirs, and better indicating when it is appropriate to issue drought "watch," "warning," and "*emergency*" declarations. The DRBC OASIS model is set up to handle ESP outputs and can test the efficacy of forecast-based operating rules.

4.13.1.5 Investigation of Water Banking and Conjunctive Use of Ground and Surface Water

Based on the information obtained and issues identified during the course of this study, HydroLogics suggests that the concepts of water banking and conjunctive use of surface and ground water be investigated as a means to increase flexibility in flow management.

In the recent past, temporary adjustments to the Decree, approved by all the parties, have set up "banks" of water in the NYC Delaware River Basin reservoirs in order to provide flexibility in meeting the needs of fisheries. These banks differ from fixed minimum flow targets because they allow the flexibility to use water when it is needed most. Banks can be established through the designation of a seasonal fixed quantity of water for a specific purpose, or banks can be "earned" by reductions in flow targets during periods when the targets can be reduced without adverse downstream impacts. Both types of banks have been used in the management of the Upper Delaware tailwater fishery. Because there are multiple objectives for the use of storage for flow augmentation and because the existing operating rules stem from court decisions on interstate water rights, water banking proposals are negotiated among the representatives of the Decree Parties and must receive the unanimous consent of the Parties prior to approval by the DRBC. Banking nevertheless represents a potential means of improving efficiency in the use of storage when it can be implemented without adversely affecting any one of the Parties.

The USGS and other agencies have conducted extensive investigations of the ground water resources of the Delaware River Basin. Some ground water models have been developed, but models which represent the interaction between ground and surface water have not been configured for water management operations. Ground water and surface water conjunctive use could substitute surface water for ground water when surface water is plentiful, thus preserving ground water for use during periods of low flow. This kind of conjunctive use might provide increased reliability for the ground water supplies while minimizing low flow impacts on streams. This type of management might be most feasible for large confined aquifers which have a delayed response to dry conditions. For fractured rock aquifers, which are affected by drought much more quickly, the practice has been to use large surface water sources to supplement ground water when well yields fall off during dry weather. The use of wells is generally cheaper than surface water due to treatment costs. A conjunctive use scheme which preserved ground water for drought periods might be useful in preventing over-drafting of aquifers and might help preserve streamflow during drought conditions. Modeling of surface and ground water interactions is recommended as a means of evaluating this concept. One of the primary purposes of this modeling is understanding the impacts of changes in the aquifer water table on streamflow. Any proposal to rely more heavily on ground water during drought would require evaluation of impacts on base flow via lowered ground water levels.

Conjunctive use with out-of-Basin supplies could work in a similar fashion. For such schemes to provide benefits to all parties, the total diversion (over time) would need to be greater (this provides the benefits to the out-of-Basin users), but the diversions would be significantly reduced below existing levels during drought (this provides benefits to the Delaware Basin. The chances of success of such a scheme would greatly depend on available out-of-basin storage.

4.13.1.6 Habitat Model Development

Attempting to assess the impacts of flows on habitat – be it trout habitat, riparian vegetation, or other – is at least as much art as science. Still, such habitat estimates are typically the only reasonable surrogate for deciding how much water to commit to preserve and enhance environmental and recreational values. Habitat models are needed wherever flow management is used to enhance ecosystem values or promote the success of individual species (e.g., trout). Several IFIM studies have attempted to quantify flow effects on trout habitat at selected locations in the Basin. Much work has been done to establish minimum releases for cold water habitat needs on the East and West Branches of the Delaware, the Neversink River, and Tulpehocken Creek, as well as the Mongaup and Lackawaxen Rivers through FERC relicensing processes. According to the NYSDEC (Sheppard), their work has focused on the base flow requirements for the life stages of aquatic species, and the results give a clear indication of the order of magnitude of the seasonal base flow requirements for the ecosystem components in general. While re-establishment of natural flow conditions is extremely unlikely, the results can be used to more closely replicate natural flow variation. The results of this work have not been presented here, but have been documented in several references (such as NYSDEC Technical Report 83-5, which recommended flow targets now being considered in negotiations by NYC and NYSDEC) and can readily be used in combination with flow modeling in flow management negotiations.

Habitat models generally should be seen as establishing trade-offs rather than thresholds. Natural flows vary considerably and most species are adapted to that variation. More flow may be better (or worse) depending on the time of year and other factors. Judicious use of habitat models can provide useful information to guide decisions about flow management, but generally are not appropriate for prescribing absolute minimum or maximum flows.

In order to enhance the credibility of habitat models and to reduce interstate disputes over evaluation methods, we recommend that DRBC create an environmental modeling oversight committee to review and standardize such efforts within the Basin. This committee should have representation (although perhaps non-voting representation) from stakeholder groups as well.

4.13.1.7 Development of Reservoir Water Quality Models

The need for reservoir water quality models has been raised in the sections above that deal with individual stream segments. Some general comments, however, are in order. Eutrophication is or may become a problem in many Basin reservoirs. Evaluating alternatives to correct such problems will require reservoir water quality models in addition to the watershed models described below. While watershed models may include reservoir and lake quality routines, they may be too crude for effective use on some of the Delaware River Basin reservoirs. Where temperature is important (most major reservoirs in the Basin), these models should include a temperature component. Temperature modeling is generally not included in the watershed models. The watershed and reservoir modeling work performed by the NYCDEP for the three NYC Delaware Basin Reservoirs could provide guidance in the development of models for other reservoirs.

Water quality problems below reservoirs may require both reservoir water quality modeling (similar to or complementing the temperature models discussed above) and instream water quality modeling. While a wide range of competent instream water quality models exists, including such models as QUAL II, the functions of water quality models are also available through the watershed models.

4.13.1.8 Maintain and Refine Monitoring Networks

The development of the information and tools recommended in this report is dependent on the data provided by the Basin's monitoring networks for water quality and quantity. For example, the USGS stream gaging network is the backbone of the inflow data set used to drive flow modeling for the Basin. Loss of monitoring capability would compromise the ability to assess trends and to model operating scenarios.

4.13.1.9 Develop More Representative Distribution of Modeled Water Demand

The projected rapid growth in the construction of gas-fired turbines to meet peak regional electrical demand is potentially an issue anywhere in the Basin. Although each case is unique, the major factors involved in siting these facilities are proximity to natural gas, electrical transmission lines, and water. DRBC's policy requires that these facilities replace the consumptive losses to the system, but current regulations do not specify where the makeup water for these facilities must be delivered.

The current DRBC OASIS model lumps consumptive use increases together at Trenton. This is satisfactory for addressing the impacts of flow management policy on Estuary salinity but is unsatisfactory for assessing impacts on tributary streams. It is recommended that DRBC's demand data be disaggregated and modeled in a more physically realistic manner. The DRBC OASIS model will easily support this disaggregation.

4.13.1.10 Development of Watershed Water Quality Models

This would include developing non-point water quality models where they do not already exist for reservoir watersheds and evaluating the feasibility of developing a non-point water quality modeling capability for the entire Delaware River Basin. These models are necessary to estimate future loadings of pollutants to reservoirs, streams, and the Estuary based on projected land use change and practices. The results can be used with reservoir, instream, or Estuary water quality models and flow modeling to understand the water quality impacts of flow management alternatives.

Watershed models predict nutrient and other pollutant loads based on land use and best management practices (BMPs). It should be possible to develop an initial, crude, Basinwide capability at low cost using EPA's BASINS system and watershed models such as SWAT. The newest versions of SWAT include OCL, which makes it possible to evaluate alternatives based on conditional operating policies. SWAT has also been partially linked to OASIS. Watershed models also include sophisticated instream water quality models, which should be used as the framework for instream water quality modeling.

4.13.2 Medium Priority Recommendations

4.13.2.1 Improve Ground Water Modeling for the Basin

Much of the water supply for the Delaware Basin comes from well fields. The USGS and other agencies have conducted extensive investigations of the ground water resources of the Delaware River Basin. Some ground water models have been developed, but models which represent the interaction between ground and surface water have not been configured for water management operations.

The DRBC, through its comprehensive planning process, expects to coordinate a Basinwide assessment of base flow characteristics. In addition, the USGS is currently developing for the DRBC a detailed ground water model of the French Creek watershed in southeastern Pennsylvania. It is recommended that the DRBC continue to pursue modeling which incorporates surface/ground water interactions as a means of investigating alternatives for flow management.

4.13.2.2 Investigate Strategies for Improving Boating Recreation

This study devoted much effort to investigating relationships between flow and the quality of the recreational boating experience. But managing flow to enhance boating involves more than a simple flow/quality of experience relationship. The timing of releases is also very important, e.g., more people will enjoy optimal recreation flows on a Saturday than will on a Tuesday. Many other types of releases (e.g., total releases for salinity repulsion) could be modified to also serve most effectively to enhance recreation. We recommend that the DRBC convene a committee to investigate strategies for using existing releases to enhance boating recreation or assign this task to an existing committee.

4.13.2.3 Develop a Coordinated Research Agenda to Identify Estuary Inflow Needs

The Trenton flow target was developed in part based on the desire to protect the Camden P-R-M aquifer from saltwater intrusion. A recent study by the USGS (Navoy, et al., 1999) indicates that the aquifer is less susceptible to salinity intrusion than previously thought. This study would seem to indicate a need to rethink the pattern of flow augmentation at Trenton and the criteria used to determine Lower Basin drought conditions in order to ensure the most effective use of stored water. We rate this as a moderate priority item because it is not clear that flow management can have a substantial effect on estuarine resources.

The specific scientific relationship between freshwater inflow and the protection of ecological resources in the Delaware Estuary should be investigated further and should include consideration of seasonal flow rates necessary to support natural resources for seasonal or migratory use. We recommend that the DRBC sponsor a colloquium to develop a coordinated research agenda for the Lower Basin focused on developing information useful for managing freshwater inflows to the Estuary and then support that research as appropriate.

Evaluating water quality impacts and changes in the Estuary will require watershed-based models for the entire Basin, as discussed above. A water quality model specific to the Estuary is also needed. Developing this model will be extremely complex and will likely involve extending the salinity model previously discussed in section 4.10.3. It will need to include salinity, BOD, DO, forms of nitrogen and phosphorus, sediment interactions, phytoplankton biomass, and chlorophyll. It may also need to include an ecological component if impacts on commercially valuable or endangered species are to be considered. DRBC already has a model for the Upper Estuary for some parameters, but developing the science base for a full model is likely to be a long term effort.

4.13.2.4 Combine NYC/DRB Versions of OASIS Model

OASIS models exist for both the Delaware River Basin and the New York City System. They overlap, but are not identical, from the NYC reservoirs down to Montague. Care was taken in developing these models to ensure that corresponding nodes had identical node numbers. Combining the two models would entail a moderate level of effort.

Currently, the DRBC OASIS model must make assumptions concerning the level of demand for NYC. Most runs are made assuming that the City takes its full allocation of 800 mgd during normal conditions, according to an annual pattern, with reductions under Watch, Warning, and Normal conditions per the Good Faith Recommendations and DRBC drought operating plans. Other runs assume lesser withdrawals during normal conditions. None of the runs reflect the changes in NYC withdrawals that result from changes in NYC's Croton or Catskill systems, nor do they reflect the withdrawals that occur at current levels of NYC demands.

Without a truly realistic estimate of NYC's current demands on the reservoirs, it is impossible for DRBC to accurately assess the impacts of changes in release strategies on conditions in the Upper Delaware Basin. In particular, the probability of occurrence of impacts cannot be estimated. Likewise, to the extent that Lower Basin conditions impact NYC reservoir releases, NYC cannot accurately assess the impacts of alternative policies on its water supplies. A combined Delaware River Basin - New York City System Model would overcome these difficulties, and would promote a fuller understanding of the impacts of changes in operating policies for all parties.

4.13.2.5 Perform a Reconnaissance Study of Potential Flow Augmentation Projects

It is likely that as new flow objectives are identified, additional storage would be needed to support these objectives. Accordingly, the feasibility of potential flow augmentation projects should be investigated. Priority should be given to expansion of existing facilities, and particularly to projects identified in Good Faith Recommendations 5 and 6 (F.E. Walter, Prompton, and Cannonsville Reservoirs).